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A Gamma process-based degradation testing of silicone encapsulant used in LED packaging

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ABSTRACT

Silicone encapsulant is widely used in light-emitting diode (LED) packaging because it offers high light transmittance, high refractive index, high thermal stability, and long lifetimes. However, it is extremely sensitive to moisture when the LED operates under high temperature and high humidity. In this study, constant moisture stress-accelerated degradation tests (CSADT) are designed with three different thermal stresses on silicone encapsulant, and its real lumen decay and color shift lifetimes are predicted by integrating the accelerated lifetime model with the Gamma process model considering the random effects of the degradation data. The results show that: (1) the lumen decay path after natural logarithmic transformation as well as the color shift degradation path can be well fitted with the linear model. In addition, the degradation rate is related to the thermal stress under the same humidity stress condition; (2) the Gamma process model has a high prediction accuracy when the lumen decay lifetime is used for estimation. On the contrary, the least squares regression (LSR) model has shown superior prediction accuracy versus the Gamma process model when color shift degradation data are used.

1. Introduction

Light-emitting diodes (LED) are one of the new generation of light sources and are gradually substituting traditional incandescent and fluorescent lamps due to their high luminous efficiency, compact size, high reliability, and environmentally friendly [1–3]. An LED package always includes an LED chip, phosphor layer, silicone encapsulant, lens, and interconnects. The degradation of any part may limit the package-level reliability [4,5]. Such reliability can be defined as the probability that, when operating under the given environmental conditions, the system will adequately perform its intended function within the specified period [6].

Lumen decay and color shift are two key failure modes for LEDs [7,8] in which the aging of silicone encapsulant as the optical material is the most important degradation mechanism [9]. Yu et al. [10] conducted high-temperature aging tests on the silicone materials used in LED chip-scale packages (CSPs) and characterized their optical, thermo-mechanical, and dielectric properties to evaluate their reliability. Fan et al. [11] used silicone/phosphor composite materials as mechanical protection and light conversion materials. They studied the effects of humidity and phosphorus on moisture absorption, hygroscopic swelling, mechanical properties, and thermal performance of silicone/phosphorus composite materials as compared to pure silicone. Fan et al. [12] evaluated the mechanical properties of phosphor/silicone composite aging under long-term high humidity conditions through tensile tests. Cai et al. [13] empirically investigated the effects of silicone lens aging on the lumen decay and color shift of LED packages under three accelerated tests: the constant stress-accelerated degradation test, step-up stress-accelerated degradation test, and step-down stress-accelerated degradation test.

To effectively assess reliability, accelerated degradation tests (ADT) were conducted under severe environmental conditions. These were developed to shorten the time for collecting data [14]. The ADT usually includes a constant-stress accelerated degradation test (CSADT), step-stress accelerated degradation test (SSADT), or progressive-stress accelerated degradation test (PSADT) [15]. The CSADT and SSADT are

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widely used because they are easily designed and conducted. For instance, Cai et al. [16] proposed a step-down-stress accelerated degradation testing (SDSADT) and step-up-stress accelerated degradation testing (SUSADT) to investigate the thermal degradation kinetics of LED lamps.

Although the least squares regression (LSR) model can more intuitively predict the trend of lumen decay and color shift, the lumen decay and color shift in LED show nonlinear changes with time, and the degradation rate does not change on average. To properly model the temporal variability of deterioration, we must rely on stochastic processes such as the Brownian motion with drift, the Poisson process, the Wiener process, and the Gamma process [17]. As compared with other stochastic processes, the advantage of using a Gamma process to model the degradation process is that the mathematical calculation is relatively simple, and the Gamma process is better at describing the degradation paths of certain products that show monotonous and gradual degradation such as in the case of crack propagation [18]. When compared with the LSR model, Gamma process models can reasonably identify the random variation in degradation process [19], and the Gamma process model can quickly improve the prediction accuracy. Duan et al. [20] discussed the design of SSADT based on a non-stationary Gamma process with random effects. Ling et al. [21] proposed the Gamma process model with CSADT whose shape and scale parameters were affected by stress levels. They applied the maximum likelihood estimation (MLEs) to obtain the average and median lifetime, conditional reliability, and residual lifetime under normal service conditions. Pan and Balakrishnan [22] proposed a multistep stress ADT model with a Gamma process that assumes that the shape parameter is a function of the stress levels and the scale parameter is a constant. Park and Kim [18] applied the Gamma process model to deal with the luminous flux degradation and chromaticity shift data of LEDs. This model describes the state and lifetime as a statistical distribution curve whose shape parameter changes with operating time. Zhang et al. [19] discussed the reliability demonstration by ADT highly-reliable products with Gamma degradation process. They assumed that the shape parameter was affected by the stress levels and the scale parameter was independent of the stress levels. Ibrahim et al. [23] proposed a stochastic approach based on Gamma Distributed Degradation (GDD) to estimate the long-term lumen decay lifetime of phosphor-converted white LEDs.

Even though silicone degradation is an important part of high-power LEDs, the prediction of LED lifetime using silicone aging data based on the Gamma process model has thus far not been studied. In this study, high temperature and high moisture aging tests were conducted on silicone, and its aging effect on LED lumen decay and color shift was predicted by integrating the accelerated lifetime model into the Gamma process model considering random effects. The remaining part of this paper is organized as follows: Section 2 introduces the accelerated degradation models used in this study including the industry recommendation and the proposed Gamma process approach. The design of the experiment, degradation aging process, and data collection are presented in Section 3. Section 4 provides the estimated results and discussions on the proposed method. Concluding remarks are given in Section 5.

2. Theory and methodology

2.1. Degradation modeling with industry recommendation

The Illuminating Engineering Society of North America (IESNA) proposed the IES TM-21 standard to predict the long-term lumen decay lifetime of LED light sources with data collected according to the IES LM-80-08 standard. The lumen maintenance degradation path model can be expressed by the following exponential model as shown in Eqs. (1) and (2) [24]:

$$\phi(t) = B \cdot e^{-\alpha t} \tag{1}$$

$$\ln\phi(t) = -\alpha t + \ln B \tag{2}$$

where $\phi(t)$ is the lumen maintenance, α is the reaction rate or degradation rate coefficient, t is the time, and $B > 0$. The $\ln\phi(t)$ is linearly related to t, and the data under each stress are fitted by the LSR model to estimate the α and B.

The lumen decay failure threshold is defined as 0.7. Thus, its lifetime can be expressed as shown in Eq. (3) [25]:

$$L_{70} = \frac{\ln\left(\frac{B}{0.7}\right)}{\alpha} \tag{3}$$

where L_{70} is the rated lumen decay lifetime. The relationship between degradation rate α and aging temperature T follows the Arrhenius model [9] as

$$\alpha = A\exp\left(-\frac{Ea}{KT}\right) \tag{4}$$

where A is the positive factor, E_a is the activation energy (eV), K is the Boltzmann constant, the value is 8.62×10^{-5} eV/K, and T is the absolute temperature (K).

The color shift path of LED can be represented by a linear degradation model as described in Eq. (5) [26,27]:

$$L(t|S_i) = \beta_i t + L_0 \quad (1 \le \mathrm{i} \le \mathrm{m}). \tag{5}$$

where $L(t \mid S_i)$ is the color shift degradation of the product, S_i is the thermal stress of the product, t is the aging time, L_0 is the initial value of the color change, and β_i is the degradation rate with constant loading condition of S_i. When the color shift path starts from 0 (L_0), Eq. (5) can be written as [27].

$$L(t|S_i) = \beta_i t \quad (1 \le \mathrm{i} \le \mathrm{m}). \tag{6}$$

2.2. Degradation modeling with Gamma process method

The Gamma process is always used to model the monotonous degradation process and the amount of degradation is $X(t)$. A Gamma process mode $\{X(t), t \ge 0\}$ is often described with the expression as follows [28]:

$$X(t) = 1 - \phi(t). \tag{7}$$

where $\phi(t)$ is the result of normalized lumen decay.

(1) $X(0) = 0$ with probability "1";
(2) $X(t)$ is an independent, non-negative random increment; and
(3) For all $t \ge 0$, $\Delta t \ge 0$, $X(t+\Delta t) - X(t) \sim Ga(u\Delta t, v)$.

The probability distribution of $X(t)$ is

$$f_{X(t)}(x) = Ga(x|u, v) \tag{8}$$

The probability density function equation is given by

$$f(x|u, v) = \frac{1}{\Gamma(u)v^u} x^{u-1}\exp(-x/v) I_{(0,\infty)}(x), x > 0 \tag{9}$$

where $I_{(0,\infty)}(x) = \begin{cases} 1 & x \in (0,\infty) \\ 0 & x \notin (0,\infty) \end{cases}$, and $\Gamma(u) = \int_0^\infty x^{u-1}e^{-x}dx$ is the Gamma function.

In modeling the product's degradation using the Gamma process, the shape parameter $u > 0$ describes the effect of stress on product performance; it is related to time and can be expressed as $u(t) = ct$, and the scale $v > 0$ stands for the effect of random factors on product performance. The expectation and the variance of $X(t)$ are

$$E(X(t)) = v \cdot u(t) \tag{10}$$

$$Var(X(t)) = v^2 u(t) \quad (11)$$

Assuming that the initial value of the Gamma degradation process is 0, the constant degradation failure threshold is ρ. Using a stochastic variable T to describe the failure time, the probability distribution function of T can be expressed as

$$F_T(t) = P(X(t) \geq \rho) = \frac{\Gamma(ct, \rho/v)}{\Gamma(ct)} \quad (12)$$

$$R(t) = 1 - F_T(t) = 1 - \frac{\Gamma(ct, \rho/v)}{\Gamma(ct)} \quad (13)$$

$$f_T(t) = \frac{d}{dt}\frac{\Gamma(ct, \rho/v)}{\Gamma(ct)} = \frac{c}{\Gamma(ct)}\int_0^{\rho/v}[\ln(\xi) - \frac{\Gamma'(ct)}{\Gamma(ct)}]\zeta^{ct-1}e^{-\zeta}d\zeta \quad (14)$$

Park and Padgett [29] proposed a simple approximate formula to estimate the average lifetime of product with the Gamma process model:

$$MTTF = \frac{\rho}{cv} + \frac{1}{2c} \quad (15)$$

2.3. Accelerated lifetime modeling

The aging test can be divided into two research methods: natural aging and accelerated aging. Natural aging usually takes several years [28]. To shorten the testing time, the accelerated lifetime model is always used to estimate the actual lifetime of the product. In the accelerated aging experiment, the acceleration factor should be considered:

$$AF = \frac{t_{normal}}{t_{stress}} \quad (16)$$

where t_{normal} is the lifetime of the LEDs aged under normal temperature and humidity, t_{stress} is the lifetime of the LED under stress conditions.

For the high temperature accelerated degradation test, the acceleration factor can be calculated according to the Arrhenius equation as expressed in Eq. (16) [30]:

$$AF_T = exp[\frac{Ea}{K}(\frac{1}{Tnormal} - \frac{1}{Tstress})] \quad (17)$$

where T_{normal} is the absolute temperature under normal conditions (273.15K), T_{stress} is temperature of the stress environments.

For high humidity accelerated life testing, the acceleration factor can be described by the Hallberg and Peck model [31]:

$$AF_H = (\frac{Hstress}{Hnormal})^{\varepsilon} \quad (18)$$

where H_{stress} is relative humidity under stress, H_{normal} is relative humidity under normal conditions; the unit is RH%, ε is the fitting parameter, and the value is 0.8 [32].

We next integrated Eqs. (16) and (17), and the high temperature and high humidity acceleration factors used in this study are

$$AF = AF_T \times AF_H = exp[\frac{Ea}{K} \times (\frac{1}{Tnormal} - \frac{1}{Tstress})] \times (\frac{Hstress}{Hnormal})^{\varepsilon} \quad (19)$$

Lumen decay and color shift lifetimes are predicted by LSR and Gamma process model, and then the error between the predicted lifetime and the actual lifetime is analyzed:

$$\eta = \frac{t_1 - t_0}{t_0} \times 100\% \quad (20)$$

where $\eta$is the error, t_1 is the predicted lifetime, and t_0 is the actual lifetime.

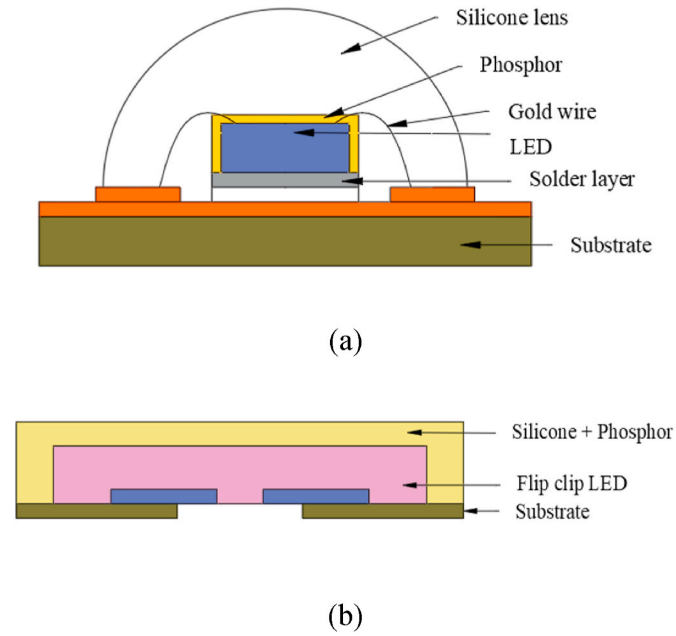


Fig. 1. The silicone encapsulant used in LED packaging: (a) traditional packaging; (b) chip-scale packaging.

3. Test sample and experiments

In this section, the test sample used in the experiment, the design of the experiment and the data collection procedure are described.

3.1. Description of test sample

The silicone material used in a LED package is shown in Fig. 1. LED packaging has evolved from the traditional packaging structure to a chip-scale-package (CSP) structure. The LED CSP is mainly composed of a flip-chip LED mold with a phosphor/silicone composite layer and is soldered on the substrate. The packaging process is simpler, and the thermal resistance is lower. However, it is exposed to external application conditions for a long time such as high temperature and high humidity. The silicone material in the phosphor/silicone composite layer will always degrade gradually when the LED is operating. Therefore, developing high-reliability silicones and evaluating their long-term life has become an important research effort to promote LEDs [10].

3.2. Experimental setup

As shown in the experiment flowchart (Fig. 2), the silicone raw materials A and B glues were firstly mixed in a mass ration of 10:1 and stirred evenly, then poured into the mold and cured at room temperature with 24 h to produce silicone encapsulant specimens with a size of 20 mm × 20 mm and a thickness of 2 mm [13]. The high temperature and high humidity aging tests were conducted within the chamber SH-641. During the experiment, moisture is an important factor affecting the aging of LED packaging materials. In this experiment, the samples were divided into three groups and aged under 65 °C/85% RH, 85 °C/85% RH, and 95 °C/85% RH for 2000 h, respectively. Here, we employed a test fixture as shown in Fig. 3, that was prepared with an unaged white LED package covered with the aged silicone encapsulant specimens, to monitor the degradation of silicone encapsulant only. After every 200h aging, the photoelectric performances of the test fixture, i.e. the lumen flux, spectral power distribution (SPD), and chromaticity coordinate, were measured by using an 0.3 m integrated sphere (HAAS-2000) [13]. According to the transmission measurements of silicone encapsulant specimens aged under different conditions [13], their transmission

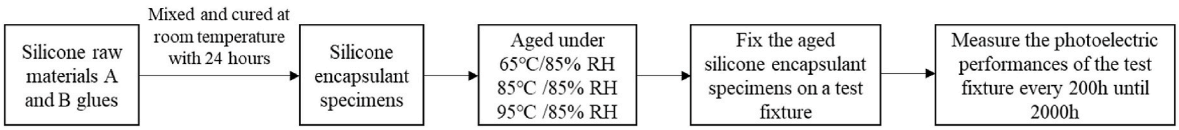


Fig. 2. The experimental flowchart.

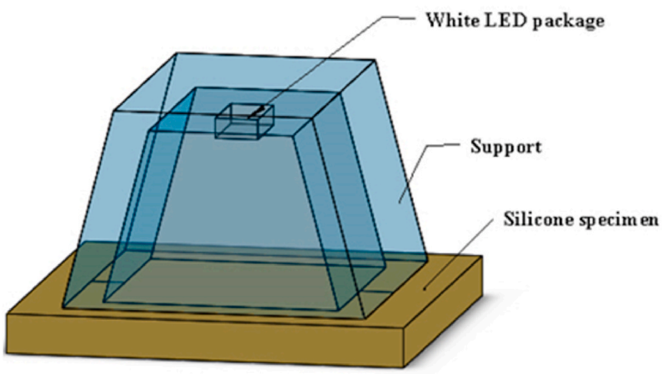


Fig. 3. The schematic diagram of the test fixture.

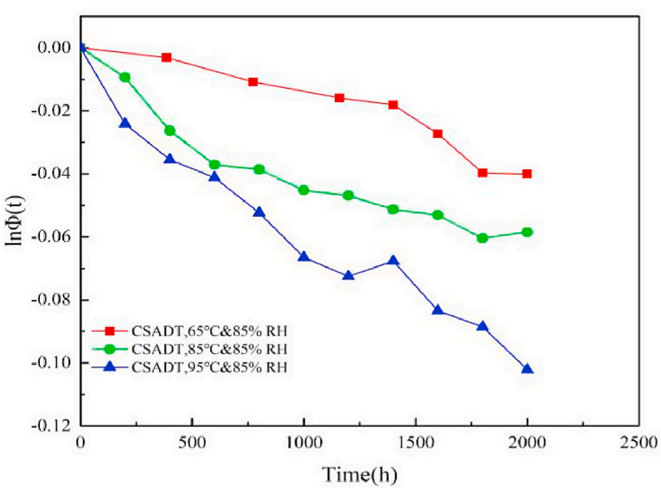


Fig. 4. The converted lumen decay path of test unit.

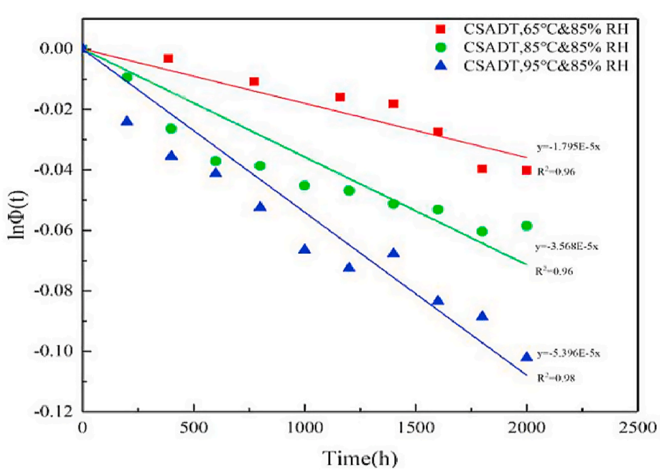


Fig. 5. The converted lumen decay curve-fittings.

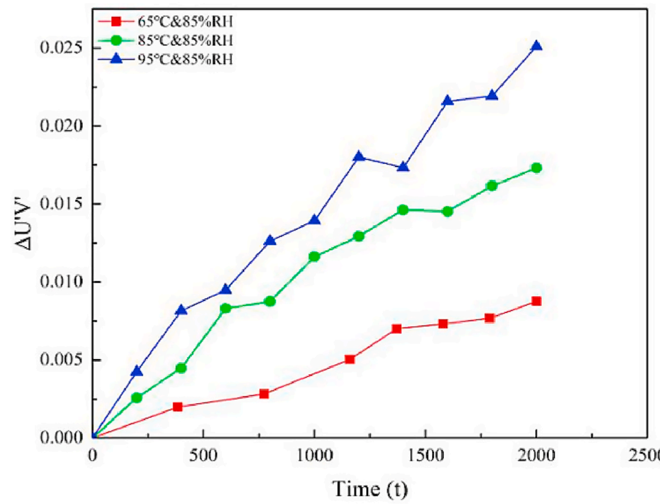


Fig. 6. Color shift path of test unit. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

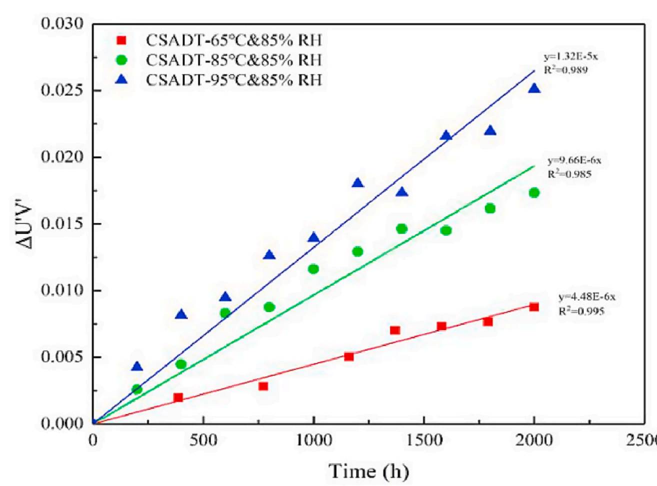


Fig. 7. Color shift curve fittings. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

spectra reduced gradually after aging, and the higher aging temperature resulted in the severer degradation. The transmittance at ~440 nm degraded much more serious than that ~570 nm, which reveals that the degradation of silicone encapsulant mainly affects the transmittance of blue light.

4. Results and discussion

4.1. Least-squares regression model

Fig. 4 shows the lumen decay paths of the test unit in CSADT. The lumen maintenance decay threshold was defined as 0.7. After conversion, the converted lumen decay threshold was ln0.7. The converted lumen decay over 2000 h did not exceed the failure threshold under any

Table 1
The lumen decay and color shift lifetime predicted by LSR model.

Groups	Lumen decay lifetime (h)	Color shift lifetime (h)
CSADT-65 °C/85% RH	19870.5	1562.5
CSADT-85 °C/85% RH	10081.3	724.6
CSADT-95 °C/85% RH	6610.0	530.1

thermal stress conditions (Fig. 4). The converted lumen decay paths of the test unit in CSADT were fitted using the linear model given in Eq. (2), as shown in Fig. 5. All goodness-of-fit (R^2) values were above 0.95, indicating that the effect of silicone material aging on the LED lumen can be reflected by the linear model of the converted LED lumen decay. The reaction rate of the fitted linear equation was the slope of the fitted curve, and the lumen attenuation was related to the temperature. This implies that the aging of the silicone encapsulant contributes to the lumen decay of test unit.

The IESNA clearly indicates that the failure threshold for the color coordinate shift of packaged equipment or modules is 0.007 [33]. Fig. 6 shows the path of color shift degradation of three groups under different aging conditions. The figure shows that the amount of color drift exceeded the failure threshold after 1500 h aging. Color shift degradation was more likely to fail compared with lumen decay. The color shift paths of the test unit were fitted using Eq. (6) (Fig. 7). The linear model fitting demonstrated that R^2 was greater than 0.98 for all aging conditions, which reveals that the linear model can also describe the effect of silicone encapsulant aging on LED color shift.

Then, the required time t for the lumen decay and color shift to degenerate to some threshold was obtained. The obtained time t was the exact failure time of the silicone sample, which is defined as the sample's actual lifetime. The extrapolation method was used to obtain the actual lifetime of lumen decay and color shift in different temperature conditions under high humidity (85% RH) as shown in Table 1. Lumen decay data after conversion from 0 to 1400 h, 0–1600 h, and 0–1800 h were taken under the conditions of 65 °C/85%RH, 85 °C/85%RH and 95 °C/85%RH, respectively. The degradation rate α was obtained by linear fitting of the converted data at 1400 h, 1600 h, and 1800 h respectively. Eq. (3) was used to calculate the predicted lumen decay lifetime under various conditions. The error of lumen decay was obtained by Eq. (20) and is detailed in Table 2. The lifetime prediction method of color shift was the same as the lumen decay. The results are shown in Table 3.

4.2. Gamma process model

4.2.1. Lumen decay lifetime estimation

To implement the proposed Gamma process for lumen maintenance predictions, the amount of degradation should satisfy the Gamma process's monotonically increasing assumption. However, the amount of degradation at 2000 h under 85 °C/85% RH and 1400 h under 95 °C/85% RH showed a decrease from the previous point, which did not satisfy the Gamma stochastic process. Thus, new points were found by applying the linear fitting method to the Gamma process model. The lifetimes under three constant temperature conditions were calculated using the Gamma model and Eq. (14) when the failure threshold of the degradation amount was $\rho = 0.3$. The curves of the reliability function $R(t)$ and cumulative failure function $F(t)$ are shown in Fig. 8. The median lifetime distributions under 65 °C/85% RH, 85 °C/85% RH, and 95 °C/85% RH were 15330 h, 8671 h, and 6257 h, respectively.

Based on the data collected at 1400 h, 1600 h, and 1800 h, the Gamma process model was used for lumen decay lifetime prediction, as shown in Table 2. Under high moisture conditions, the lumen decay lifetime of silicone samples decreased with increasing temperature, and the accuracy of lumen decay lifetime prediction increased with the more amount of test data. Upon comparing the Gamma process model with the LSR model, we see that the accuracy of the Gamma process model is relative higher when predicting the lifetime of lumen decay.

4.2.2. Color shift lifetime estimation

Under the three constant temperature aging conditions, all color shift data satisfy the nature of the Gamma process. The given failure threshold ρ of the color shift is 0.007 and the lifetimes under three constant temperature conditions were calculated using the Gamma process model and Eq. (14). These calculations led to the reliability function $R(t)$ and cumulative failure function $F(t)$ curves shown in Fig. 9. The median lifetime distributions at 65 °C/85%RH, 85 °C/85%RH, and 95 °C/85%RH were 1623 h, 832 h, and 581 h, respectively. Based on the data collected at 1400 h, 1600 h, and 1800 h, the Gamma process model was used for color shift lifetime predictions as shown in Table 3.

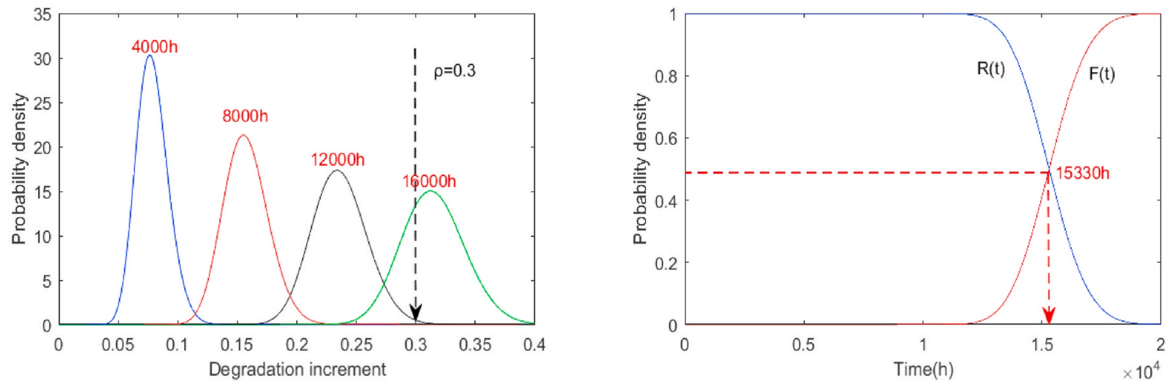
Temperature is an important factor affecting the color shift temperature under high moisture. The estimation results show that the prediction results based on the LSR model offer high accuracy versus the Gamma process model. When predicting the color shift lifetime, the degradation of the color shift amount under all conditions failed within 1600 h, and the time used for prediction is close to or has exceeded the actual lifetime, which results in the LSR model being better than the

Table 2
Comparison of lumen decay lifetime based on Gamma process model and LSR model.

	65 °C/85%RH			85 °C/85%RH			95 °C/85%RH		
Test duration (h)	1400	1600	1800	1400	1600	1800	1400	1600	1800
Gamma lifetime (h)	23483.6	17843.2	18721.6	8461.8	9345.5	9772.1	5832.7	6045.3	6416.5
Actual lifetime (h)	19870.5	19870.5	19870.5	10081.3	10081.3	10081.3	6610.0	6610.0	6610.0
Prediction error of Gamma model (%)	18.18	−10.21	−5.78	−16	−7.3	−3.07	−11.76	−8.54	−2.93
LSR lifetime (h)	27102	24263.6	20908.8	8335.3	8988.8	9401.8	5799.6	5994.5	6353.3
α*E-05	1.32	1.47	1.71	4.27	3.97	3.79	6.15	5.95	5.49
Prediction error of LSR model (%)	36.39	22.11	5.59	−17.32	−10.84	−6.74	−12.26	−9.31	−3.88

Table 3
Comparison of color shift lifetime based on Gamma process model and LSR model.

	65 °C/85%RH			85 °C/85%RH			95 °C/85%RH		
Test duration (h)	1400	1600	1800	1400	1600	1800	1400	1600	1800
Gamma lifetime (h)	1433.9	1572.4	1690.1	697.6	757.6	818.5	512.9	547.6	608.7
Actual lifetime (h)	1562.5	1562.5	1562.5	724.6	724.6	724.6	530.1	530.1	530.1
Prediction error of Gamma model (%)	−8.23	0.63	8.16	3.73	4.56	12.93	−3.22	3.31	14.3
LSR lifetime (h)	1525.1	1528.4	1566	630	673.1	698.6	489.5	500	518.5
α*E-05	0.459	0.458	0.447	1.11	1.04	1.00	1.43	1.40	1.35
Prediction error of LSR model (%)	−2.39	−2.18	0.22	−13.06	−7.1	−3.59	−7.60	−5.68	−2.19



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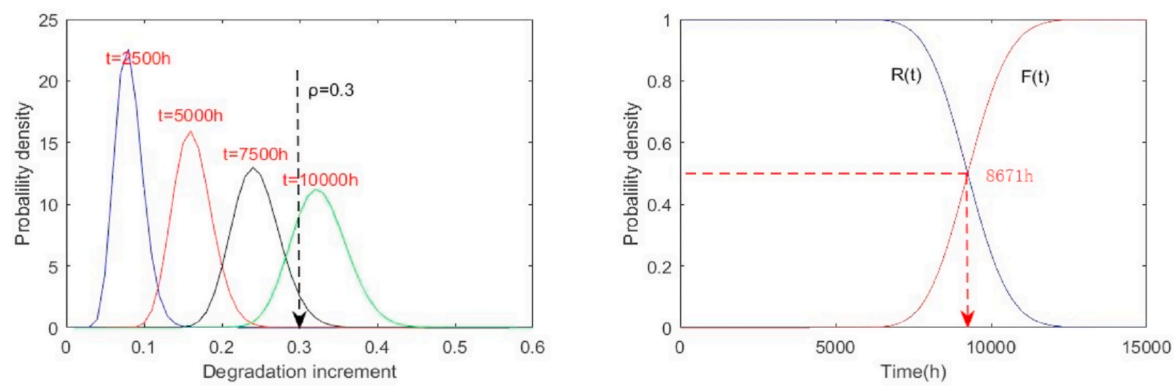

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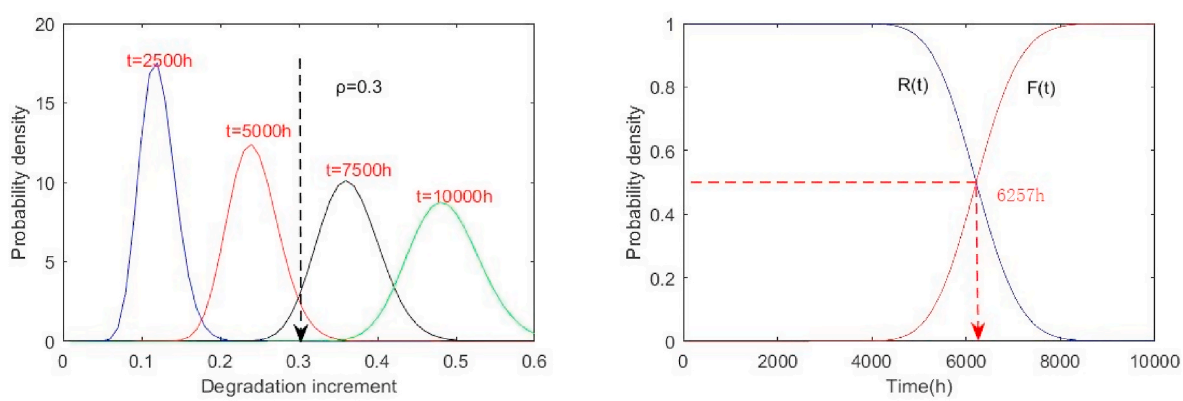

(c)

Fig. 8. The reliability function $R(t)$ and cumulative failure function $F(t)$ of lumen decay lifetime at different aging conditions: (a) 65 °C/85% RH; (b) 85 °C/85% RH; (c) 95 °C/85% RH.

Gamma process model.

Finally, it is concluded that the Gamma process model has a high accuracy in predicting the lumen decay of silicone while the LSR model can predict the color shift of silicone. Referring to the IESNA standards [25,33], both lumen decay and color shift are two most important degradation failure modes for the reliability of white light LEDs [34]. Thus, we modeled the degradation of silicone encapsulant under high temperature and high humidity conditions through considering both failure modes. By using Eqs. (16) and (19), the lumen decay and color shift lifetimes under a normal condition of 25 °C/50% RH were predicted based on the Gamma process model and the LSR model, respectively and the results were displayed in Table 4.

5. Conclusions

In this paper, accelerated degradation tests were conducted using CSADT at 65 °C, 85 °C, and 95 °C under a high humidity environment. The lumen decay and color shift of silicone were predicted and compared via the Gamma process model and LSR model. The following conclusions can be drawn:

1) The natural logarithm transformed lumen maintenance degradation path and the color shift path can be well fitted with the linear model. The degradation rate is related to the thermal stress under the same

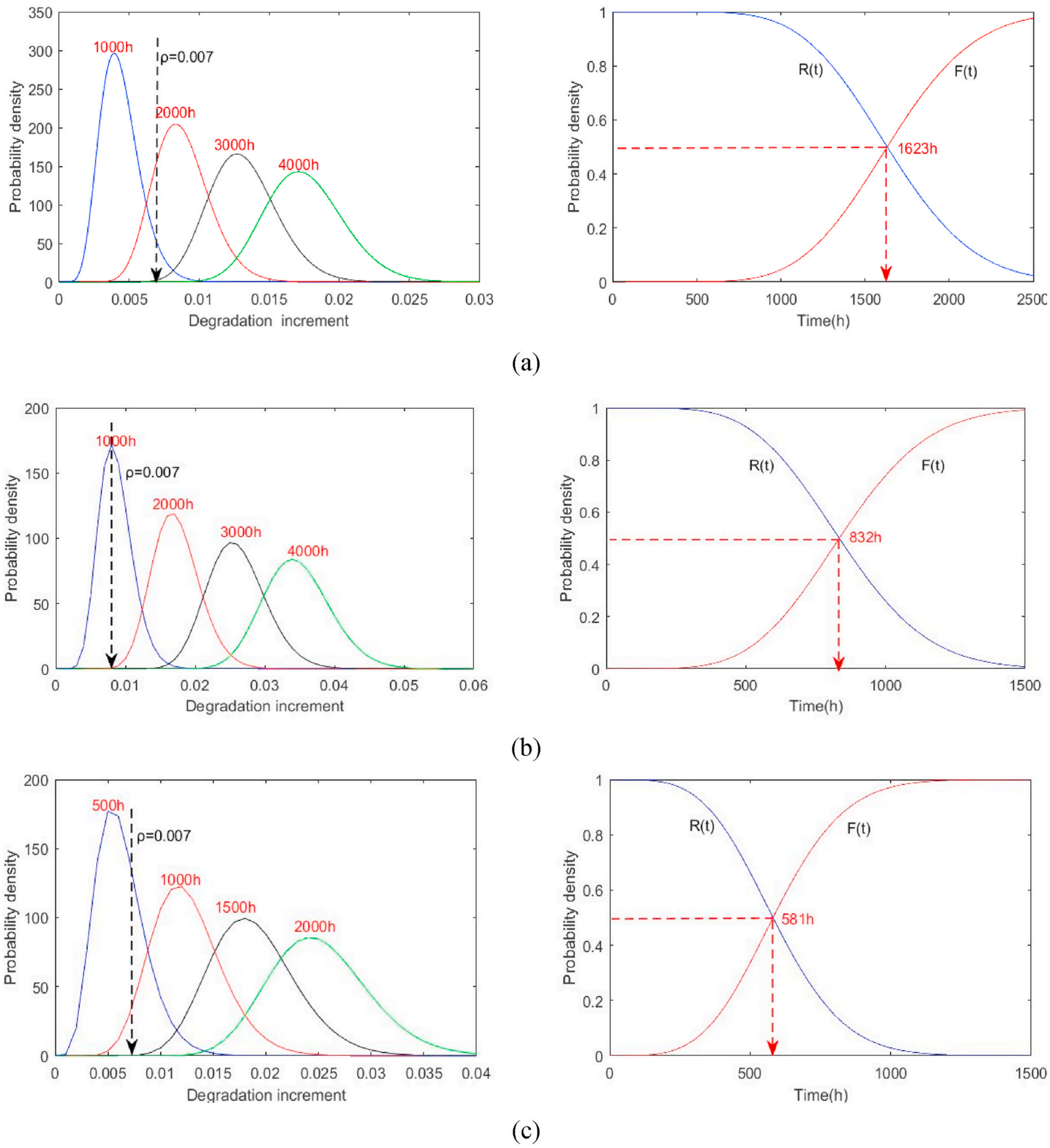

Fig. 9. The reliability function $R(t)$ and cumulative failure function $F(t)$ of color shift lifetime at different aging conditions: (a) 65 °C/85% RH; (b) 85 °C/85% RH; (c) 95 °C/85% RH. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 4
The predicted lumen decay and color shift lifetime under 25 °C/50% RH.

	Lumen decay			Color shift		
Temperature (°C)	65–85	65–95	85–95	65–85	65–95	85–95
Acceleration factor (*AF*)	1.77	2.45	1.39	2.16	2.95	1.37
Activation energy (eV)	0.2981	0.3205	0.3743	0.4010	0.3866	0.3553
Lifetime at 25°C/50% RH (*h*)	92442.8	100659.6	156093.5	15766.4	14156.5	11232.4

humidity stress conditions and a higher temperature leads to a greater degradation rate.

2) The Gamma process model is quite precise when the lumen decay lifetime is predicted. However, the LSR model is superior to the Gamma process model when a color shift lifetime is predicted. Therefore, the model with higher accuracy was selected in accelerated lifetime modeling to predict the lumen decay and color shift of silicone under normal temperature and constant humidity.

To meeting the increased complexity of LED applications, the multiphysics conditions, coupling with the effect of high temperature, high sulfur, high humidity, and high optical radiation, will be considered in the future for the silicone encapsulant materials. Furthermore, the multiphysics conditions will bring multiple degradation mechanisms and their interactions, that needs deep learning methods to handle the complexity with high nonlinearity and multivariate relationships.

CRediT authorship contribution statement

Jiajie Fan: Conceptualization, Methodology, Formal analysis, Writing - review & editing, Project administration, Funding acquisition. **Ye Chen:** Experiments, data collection and analysis, Writing - original draft. **Zhou Jing:** Modeling, Methodology. **Mesfin Seid Ibrahim:** Modeling, Methodology. **Miao Cai:** Provide data, Funding acquisition.

Declaration of competing interest

All authors declare no conflict of interest.

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